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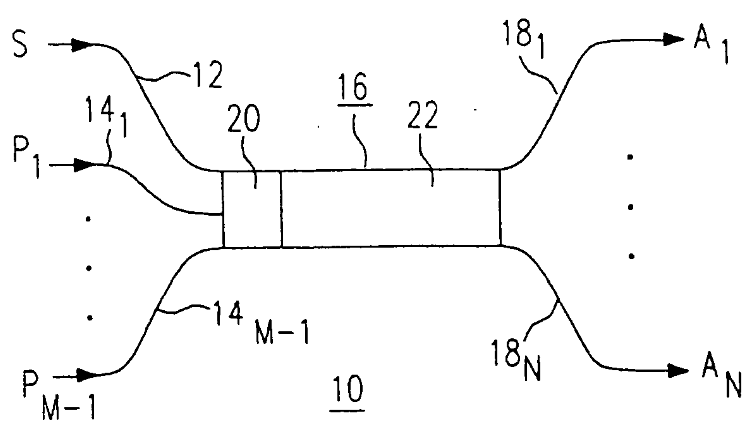
(54) **Optical star coupler utilizing fiber amplifier technology.**

(57) An MxN optical star coupler is disclosed which utilizes fiber amplifier technology to provide amplification of message signals. The input signals to the star comprise at least one message signal (S) and at least one pump signal (P_1 -P_{M-1}). The message signals and pump signals combine in an amplifier coupling region (16) to form as an output the amplified message signals (A_1-A_N). The amplified message signals are then coupled into the plurality of N output waveguides (18_1-18_N). In one embodiment, a plurality of fiber amplifiers are coupled in a one-to-one relationship to the plurality of output waveguides. Since the amplifier is reciprocal in nature, the star may be utilized as a bidirectional device. The couplers may also be connected together to form a cascaded arrangement capable of providing re-amplification of the message signals.

FIG. 1



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Background of the Invention

Field of the Invention

The present invention relates to an optical star coupler and, more particularly, to an MxN amplified star coupler.

Description of the Prior Art

Rare earth-doped fiber amplifiers are beginning to find a wide variety of uses in optical communication systems. In particular, such amplifiers have been suggested for use in multichannel distribution networks. An article entitled " 16-Channel Optical FDM Distribution/Transmission Experiment Utilizing Er^{3+} -Doped Fibre Amplifier", by H. Toba et al. appearing in Electronics Letters, Vol. 25, No. 14, July 1989, discusses one such broadcast arrangement. In particular, Toba et al. describe a system where sixteen DFB lasers, operating at 5 GHz frequency intervals, are applied as inputs to a 16 x 16 star coupler. The multiplexed signals at each output port are then combined with a pump laser operating at 1.48 μm and applied as an input to an isolated Er^{3+} -doped fiber amplifier. The amplified signals are then transmitted over single mode fiber to the predefined destination. The arrangement as described utilizes a discrete fiber amplifier arrangement (i.e., pump source, couplers, doped fiber) for each of the sixteen output fibers. For large systems, the number of additional components required to provide amplification may become cost and size prohibitive.

Thus, a need remains in the art for a viable communication alternative which exploits the benefits of fiber amplifiers, without incurring the limitations as discussed above.

Summary of the Invention

The need remaining in the prior art is addressed by the present invention which relates to a fiber optic star coupler and, more particularly, to an MxN amplified star coupler.

In accordance with one embodiment of the present invention, a star coupler is formed which includes a plurality of M input optical waveguides and a plurality of N output optical waveguides (where M may be equal to N and the waveguides may comprise optical fibers, thin-film waveguides, or any other suitable medium capable of providing optical transmission). A plurality of L message signals ($1 \leqq L < M$) are applied as inputs to L of the M input waveguides. At least one of the remaining M-L input waveguides is coupled to a laser pump source. Disposed between the input and output waveguides is an amplifier coupling region capable of directly mixing the message signals with the pump signals to provide amplification of the input message signals. The amplifier coupling region may comprise a fiber amplifier, a thin-film optical amplifier, or any other arrangement suitable of providing optical amplification. The amplified message signals are subsequently coupled into the plurality of N output waveguides.

Brief Description of the Drawing

Referring now to the drawings, where like numerals represent like parts in several views:

FIG. 1 illustrates an exemplary MxN amplified star of the present invention which includes a single message source S and a plurality of M-1 pump sources, utilizing a single fiber amplifier coupling region;

FIG. 2 illustrates an alternative MxN amplified star including a plurality of L message sources and a plurality of M-L pump sources, utilizing a plurality of N fiber amplifiers to form the coupling region between the input fibers and the output fibers;

FIG. 3 illustrates yet another embodiment of the present invention, particularly illustrating the use of a plurality of separate fiber amplifiers associated with each output fiber, as well as the ability to provide bidirectional communication through the amplified star of the present invention;

FIG. 4 illustrates an alternative bidirectional amplified star of the present invention, with signal and pump sources located at both the input and output of the star arrangement;

FIG. 5 illustrates an embodiment of the present invention where only selected output fibers are configured to include fiber amplifiers; and

FIG. 6 illustrates an alternative arrangement utilizing a plurality of the amplified stars of the present invention configured in cascaded form for providing subsequent re-amplification of the transmitted message signal(s).

Detailed Description

FIG. 1 illustrates an exemplary MxN amplified star 10 of the present invention particularly suited for applications where it is desired to transmit a single message signal S to a large number of destinations. Amplified star 10 includes an input fiber 12 which is coupled to a signal source (not shown) such that a first message signal S enters star 10. It is to be understood that the various input and output optical signal paths, and amplifying regions, depicted in the following embodiments are shown as comprising optical fibers for illustrated purposes only. As mentioned above, these various components may comprise, in the alternative, thin-film optical waveguides or any other suitable optical communication medium. In particular,

with respect to the amplifier coupling region, one embodiment may comprise the utilization of an external light source which illuminates a region where both the message and pump signals exist (referred to in the art as "side-pumped" amplification).

Returning to the description of FIG. 1, the remaining M-1 input fibers 14_1 - 14_{M-1} are coupled to a plurality of pump sources (not shown) so as to receive a plurality of M-1 pump signals, denoted P_1 - P_{M-1} in FIG. 1. In general, only one such pump source is required, with the remaining inputs either connected to additional pump sources (to supply the required power), or left unconnected. As illustrated, amplified star 10 comprises a fused fiber coupler where input fibers 12, 14_1 - 14_{M-1} are joined in a coupled region 16 to a plurality of N output fibers 18_1 - 18_N. In accordance with this particular embodiment of the present invention, coupling region 16 comprises a signal combiner 20 and a fiber amplifier 22. As shown, the plurality of M input fibers 12,14_1 - 14_{M-1} are attached to combiner 20 so as to provide the coexistence of message signal S and the plurality of pump signals P_1 - P_{M-1} within combiner 20. The combined signals subsequently enter fiber amplifier 22 where message signal S is amplified and coupled into the plurality of output fibers 18_1 - 18_N . The plurality of N amplified message signals A_1 - A_N are illustrated in FIG. 1. The doping of fiber amplifier 22 and wavelength of the associated pump signals P_1 - P_{M-1} are chosen to provide the desired amplification of message signal S. For example, the combination of an erbium-doped fiberamplifier and pump sources having a wavelength of approximately 1.47μm -1.49 μm has been found to provide sufficient amplification of message signals at a wavelength within the range of, for example, 1.54 μm - 1.56 μm. Other material dopants, such as Nd^{3+}, Ho^{3+}, Cr^{3+} (ruby) may also be used, in association with the appropriate pump and signal wavelengths for each medium and dopant.

An alternative MxN amplified star 30 of the present invention is illustrated in FIG. 2. In this arrangement, a plurality of L (L<M) message signals S_1 - S_L are applied as inputs to a plurality of fibers 12_1 - 12_L. The remaining M-L input fibers 14_1 - 14_{M-L} are coupled to receive pump signals P_1 - P_{M-L}, respectively. As shown in FIG. 2, message signal S_L and pump signal P_1 are applied as inputs to a wavelength division multiplexer 34. Multiplexer 34 subsequently provides as an output a combination S_L P_1 which propagates along a single input fiber, denoted 15. Although exemplary in nature, such wavelength division multiplexing may be utilized at various inputs associated with this or any other embodiment of the present invention. As with amplified star 10 of FIG. 1, input fibers 12_1 - 12_{L-1}, 15, and 14_2 - 14_{M-L} of star 30 are coupled through fiber amplifier coupling region 16 to output fibers 18_1 - 18_N. In this example, fiber amplifier coupling region 16 comprises a plurality of N sections of fiber amplifier 32_1 - 32_N, coupled in a one-to-one relationship with the plurality of N output fibers 18_1 - 18_N. Fiber amplifiers 32_1 - 32_N are coupled to both message signal input fibers 12_1 - 12_L and pump signal input fibers 14_1 - 14_{M-L}, as shown in FIG. 2, to form a combining region 36 (similar in form and function to signal combiner 20 of FIG. 1) wherein message signals S_1 - S_L and pump signals P_1 - P_{M-L} will coexist. The combined signals will therefore be amplified as they pass through each fiber amplifier 32_I associated with each output fiber 18_I . A plurality of wavelength dependent elements 38_1 - 38_N may be disposed between fiber amplifiers 32_1 - 32_N and fibers 18_1 - 18_N to essentially remove the pump signals from propagating along the output fibers. Elements 38_1 - 38_N may comprise wavelength selective filters, demultiplexers, or other similar devices capable of blocking (or introducing) the propagation of the predetermined pump wavelength.

As a result of the reciprocal nature of fiber amplification, the MxN amplified star of the present invention may be utilized as a bidirectional device. An exemplary bidirectional MxN amplified star 40 is illustrated in FIG. 3. Similar to star 30 of FIG. 2, a plurality of L message signals S_1 - S_L and a plurality of M-L pump signals P_1 - P_{M-L} are applied as inputs to fibers 12_1 - 12_L and 14_1-14_{M-L}, respectively, of amplified star 40. These signals subsequently mix together within a combining region 42 and subsequently propagate along a plurality of interconnecting fibers 44_1 - 44_N to a plurality of fiber amplifiers 46_1 - 46_N, as shown in FIG. 3. The amplified output signals, denoted A_1 - A_N, from the plurality of fiber amplifiers are then coupled into the plurality of output fibers 18_1 - 18_N . As shown in FIG. 3, a return communication signal R is coupled to an exemplary output fiber 18_I so as to propagate in the opposite direction through fiber amplifier 46_I. It is to be noted that a single return signal is illustrated in FIG. 3 for the sake of clarity. In general, a plurality of J ($J \leqq N$) such signals may be transmitted. As with the forward-directed signals, return signal R and pump signals P_1 - P_{M-L} must co-exist in fiber amplifier 46_I to provide the desired amplification of return signal R. The direction of travel of the signals is not material to the operation of such fiber amplifiers. Referring to FIG. 3, amplified return signal AR will exit fiber amplifier 46_I and be coupled via combining region 42 into input fibers 12_1 - 12_L, 14_1 -14_{M-L}. In some cases, a plurality of K input fibers may be prevented from receiving the return message signal by including an isolator 48_I in each of the K input fibers.

In general, a bidirectional amplified star of the present invention may be formed to include pluralities of message and pump sources on each side of the star. One exemplary bidirectional amplified star 50 is illustrated in FIG. 4. Amplified star 50, shown as an MxN star, utilizes as inputs a first plurality of L message signals S_1 - S_L, a first plurality of M-L pump sour-

ces P_1 - P_{M-L} (where these signals are coupled to fibers 12_1 - 12_L and 14_1 - 14_{M-L}, respectively), a second plurality of J message signals R_1 - R_J and a second plurality of N-J pump sources PR_1 PR_{N-J} (where these signals are coupled to fibers 18_1 - 18_J, 18_{J+1} - 18_N, respectively). Similar to the arrangement of FIG. 1, the amplification of the message signals occurs in a fiber amplifier coupling region 52 disposed between the fiber groups. In this particular embodiment, coupling region 52 comprises a fiber amplifier 54 disposed between a first signal combiner 56 and a second signal combiner 58. In operation, first signal combiner 56 mixes together the first pluralities of the message signals S_1 - S_L and pump sources P_1 - P_{M-L} before they enter fiber amplifier 54. As discussed above, the message signals, in the presence of the pumps, will be amplified in fiber amplifier 54 and emerge as an amplified message signal A which is then coupled into the plurality of N output fibers 18_1 - 18_N. Similarly, second signal combiner 58 mixes together the second pluralities of message signals R_1 - R_J and pump sources PR_1 - PR_{N-J} appearing at the output fibers, coupling the combined signals into fiber amplifier 54. The amplified return signal AR subsequently passes through first signal combiner 56 and is coupled into the plurality of M input fibers. It is to be noted that it is not necessary to include a plurality of pump sources along fibers 18 output of bidirectional amplified star 50, since return signals R_1 - R_J may be configured to pass through fiber amplifier simultaneously with the first plurality of pump sources P_1 - P_{M-L}, where as mentioned above, simultaneous existence of the message and pump is the only requirement to obtain amplification of the message signal.

In some applications, it may not be necessary to provide amplification along each output fiber. For example, a number of receiving locations may be located sufficiently close to the star coupler such that amplification of the message signals is not required. Accordingly, an amplified star 60 of the present invention, illustrated in FIG. 5, may be formed so as to include fiber amplifiers along only selected output fibers. Star 60, which is simplified to an Mx4 star for illustrative purposes only, includes a pair of output fibers 18_2, 18_3 which require no amplification, since a pair of receiving devices 62_2, 62_3 are located in relative close proximity to coupler 60. The remaining pair of output fibers 18_1, 18_4 are illustrated as including a pair of fiber amplifiers 64_1, 64_4, respectively, similar in form and function as those described above in association with FIG. 3. To prevent the unwanted transmission of the pump signals along fibers 18_2, 18_3, a pair of wavelength selective elements 66_2, 66_3, of a type previously described, may be included along their respective output fibers. It is to be understood that such an amplified star arrangement of the present invention may easily be modified during the course of its operation to either include or remove certain fiber amplifiers from the various output fibers as the requirements for the system including the inventive coupler change. Additionally, such an amplified star of the present invention may be further modified by adjusting the particular length of each fiber amplifier segment used to provide the fiber amplification. As is known in the fiber amplifier art, the amount of amplification is related to the length of the fiber segment. In general, increasing the length of the fiber segment will result in increased amplification, as long as sufficient pump signal remains. Alternatively, if it is desired to reduce the amount of amplification along a particular output path, the length of fiber amplifier may be suitably shortened.

An extended star coupler amplifying arrangement 70 is illustrated in FIG. 6. The initial section 72 of arrangement 70 is similar to amplified star 40 of FIG. 3, including a signal combining region 74 and a plurality of fiber amplifiers 76. However, instead of being directly coupled to receivers, selected ones of the plurality of output fibers 18 in section 72 are applied as inputs to a second tier of fiber amplified stars 72′. Such additional amplification may be required in instances where the signal travels a significant distance (e.g., ten or more kilometers), where the exact distance depends upon many factors, including the composition of the fiber itself (i.e., glass vs. plastic fiber vs. titanium-diffused lithium niobate, etc.). The amplification process may be continued a number of times, with an exemplary third tier fiber amplified star 72″ illustrated in FIG. 6. It is to be understood that such a cascaded arrangement may include the various wavelength selective elements and isolators described above in association with FIGs. 2 and 3.

Claims

1. An optical star coupler comprising

   a plurality of M input waveguides (e.g., 12, 14), with L ($1 \leqq L<M$) waveguides (e.g., 12) coupled to receive a plurality of L message signals and at least one of the remaining M-L waveguides (e.g., 14) coupled to receive optical pump signals;

   a plurality of N output waveguides (e.g., 18); and

   a doped fiber amplifier coupling region (e.g., 16) disposed between the plurality of M input waveguides and the plurality of N output waveguides to provide the mixing of the message signals and the pump signals such that a plurality of N amplified message signals are generated and coupled into the plurality of N output waveguides.

2. An optical star coupler as defined in claim 1 wherein the doped fiber amplifier coupling region

comprises

a signal combiner (e.g., 20) attached to the plurality of M input waveguides for providing the optical combining of the various message and pump input signals; and

a doped fiber amplifying section (e.g., 22) attached to the output of the signal combiner for providing the amplification of the plurality of L message signals.

3. An optical star coupler as defined in claim 1 wherein the doped fiber amplifier coupling region comprises

a signal combiner (e.g., 36) attached to the plurality of M input waveguides for providing the optical combining of the various message and pump input signals; and

a plurality of N doped fiber amplifying sections (e.g., 32) disposed between the signal combiner and the plurality of N output waveguides such that the plurality of N amplifying sections are coupled in a one-to-one relationship with said plurality of N output waveguides.

4. An optical star coupler as defined in claim 1 wherein the doped fiber amplifier coupling region comprises

a signal combiner (e.g., 42) attached to the plurality of M input waveguides for providing the optical combining of the various message and pump input signals;

a plurality of N interconnecting waveguides (e.g., 44) attached to the output of said signal combiner, and

at least one doped fiber amplifying section (e.g., 46) coupled between at least one interconnecting waveguide and at least one output waveguide.

5. An optical star coupler as defined in claim 4 wherein the at least one doped fiber amplifying section comprises a plurality of N amplifying sections coupled in a one-to-one relationship with the plurality of N output waveguides.

6. An optical star coupler as defined in claim 1 wherein the coupler further comprises wavelength selective means (e.g., 66) disposed at the output of the doped fiber amplifier coupling region for essentially removing the pump signal from the amplified message signals.

7. An optical star coupler as defined in claim 6 wherein the wavelength selective means comprises a plurality of N wavelength selective elements disposed along each output waveguide of the plurality of N output waveguides.

8. An optical star coupler as defined in claim 1 wherein the coupler further comprises at least one wavelength division multiplexer (e.g., 34) for receiving as separate inputs a message signal and a pump signal and providing as an output to the amplifier coupling region, on a single waveguide, the combination of the message signal and the pump signal.

9. An optical star coupler as defined in claim 1 wherein the star operates as a bidirectional coupler (e.g., 50) with at least one output waveguide coupled to receive a return message signal.

10. An optical bidirectional star coupler as defined in claim 9 wherein the coupler further comprises a plurality of K optical isolators disposed along a selected plurality of K input waveguides associated with a selected plurality of K message signals, said isolators capable of essentially blocking the propagation of the return message signal.

11. An optical bidirectional star coupler as defined in claim 9 wherein the coupler comprises a plurality of J return message signals coupled to a plurality of J output waveguides and at least one return pump source coupled to at least one of the remaining N-J output waveguides.

12. An optical star coupler as defined in claim 1 wherein the optical pump signals operate at a wavelength within the range of approximately 1.47 μm -1.49μm, and the doped fiber amplifier coupling region comprises an erbium-doped fiber amplifier.

13. An optical star coupler as defined in claim 1 wherein $L=1$.

14. An optical star coupler as defined in claim 1 wherein $1 \leqq L \leqq M$.

15. An optical star coupler as defined in claim 1 wherein at least one of the plurality of M input waveguides and the plurality of N output waveguides comprises an optical fiber.

16. An optical star coupler as defined in claim 15 wherein the plurality of M input waveguides comprises a plurality of M optical fibers and the plurality of N output waveguides comprises a plurality of N optical fibers.

17. An optical star coupler as defined in claim 1 wherein at least one of the plurality of M input waveguides and the plurality of N output waveguides comprises a thin-film optical

waveguide.

18. An optical amplifying arrangement comprising a plurality of star couplers as defined in claim 1, the plurality of couplers disposed so as to form a cascaded arrangement capable of providing subsequent re-amplification of the transmitted message signals.

FIG. 1

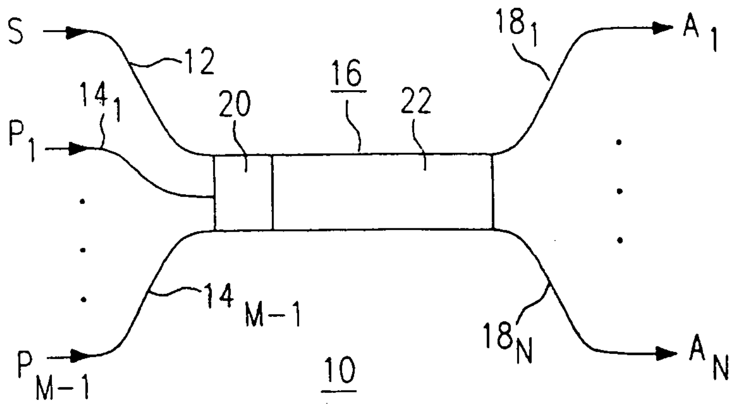


FIG. 2

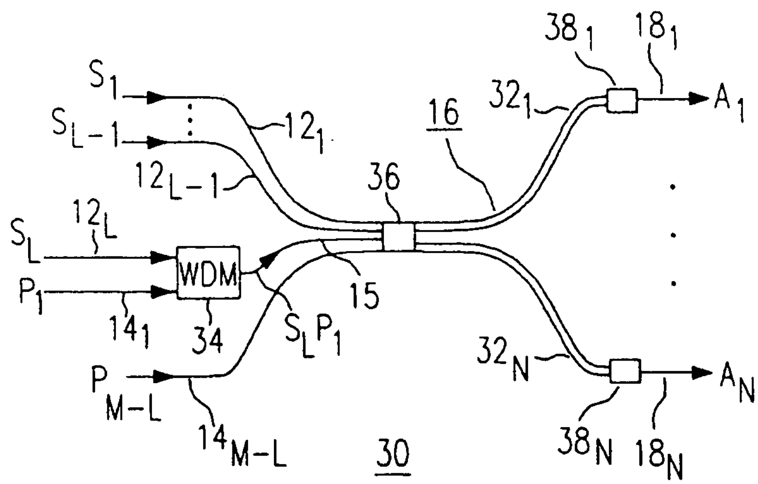


FIG. 3

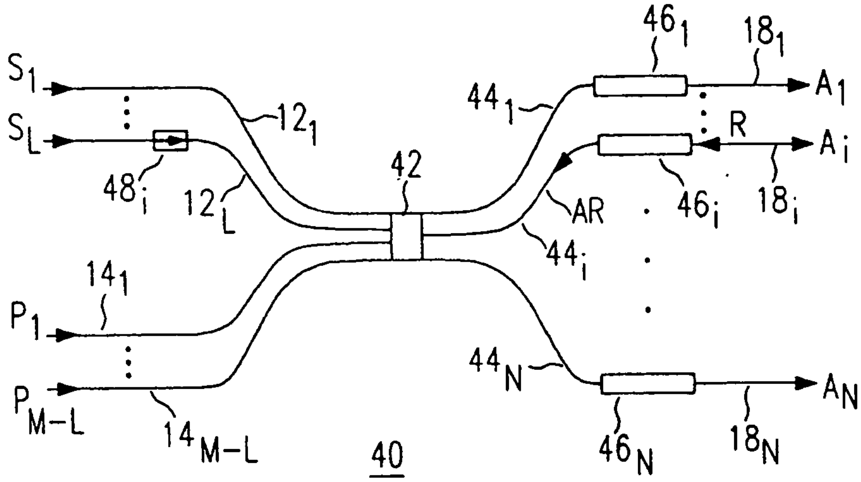
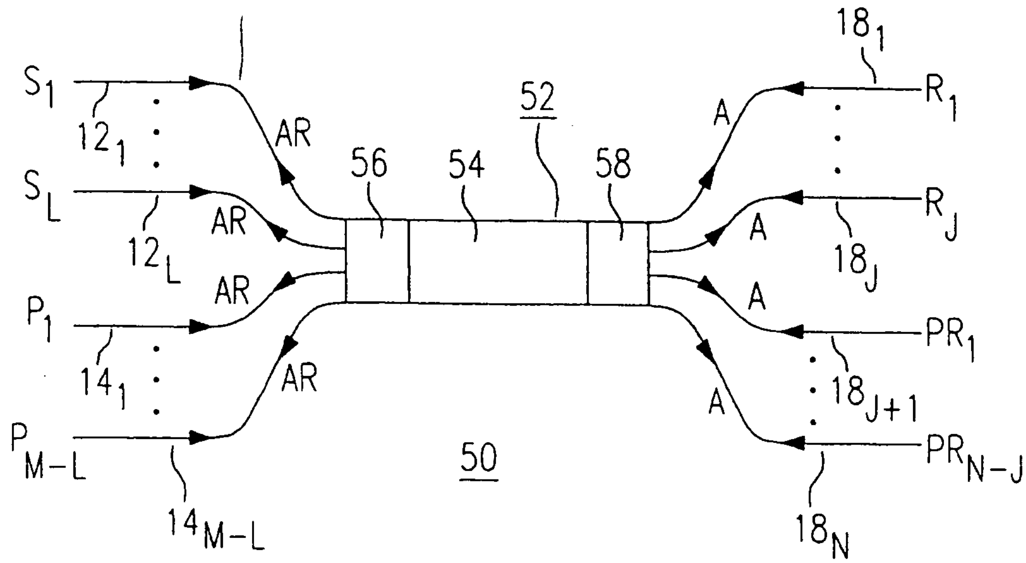


FIG. 4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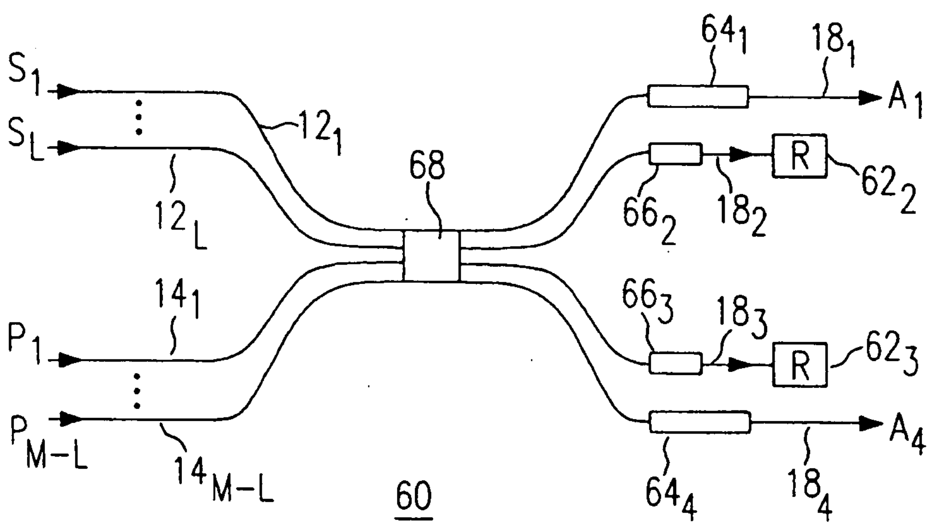
PRN-J
18N

FIG. 5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A1
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66 3
18 3
R
62 3
64 4
18 4
A4

FIG. 6